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FINANCIAL MODELING FOR OPERATING MINES:
SHORT-FORM EVALUATION TECHNIQUES

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Abstract:

For operating mines, the market or mining conditions can unexpectedly change requiring quick decision making and adjustments under time and environment pressure. Conducting a thorough complex DCF analysis is a very long process that can lead to inefficiencies and erroneous decisions during critical and pressuring conditions. An organized and well-structure financial model for operating mines can be streamed down with short-form evaluation techniques, VBA Macros, and quick reporting tools to quickly conduct DCF and sensitivities analyses of mine plans to speed up the assessment of how the operating mine can adjust to these unexpected changes.

Keywords: *Mining, Modeling, Finance, Valuation*

I.- INTRODUCTION

"If you have turned on a light, entered a building, driven on a road, made a phone call, used a computer, or visited a doctor, then mining is part of your life," mentions the National Mining Association (2017) from the United States. Mining involves the extraction of valuable mineral resources including metals, coal, aggregates, and others. An operating mine could be an open-pit, underground, or a combination of both. The best mining method is chosen based on the natural conditions of the deposit. To understand key information from technical reports, it is important to define a resource and a reserve. Resources are the "in situ mineral occurrences" which are categorized as inferred, indicated, and measured depending on the level of confidence. An indicated and measured ore resource can become a reserve if it is economically viable to extract (Rudenno, 2009, 88). Mining and production schedules obtained from technical reports or feasibility studies are usually prepared by mining engineers; the final financial evaluations are conducted by accounting departments to determine the mine's NPV.

The typical mine evaluation process for new projects involve a feasibility study, a discounted cashflow analysis, and sensitivity analysis. However, these analyses apply to only a certain set of conditions for which the project was originally expected to operate by. For operating mines, the market or mining conditions can unexpectedly change which requires decisions to be made under time and environment pressure; therefore, conducting a typical detailed evaluation process can put in risk the viability of an operation. For example, if a mine does not adjust quick enough to new commodity prices, it can lead to tremendous profit margin reduction and, possibly, lead to its closure. "The difference in performance rests with the ease or difficulty in implementing (ongoing) change," denotes Ian C. Runge (1998, 187), a corporate advisor on capital investment strategy whose expertise extends to mining technology, and is recognized as a world authority in mining economics and mine design.

The idea and importance for this project comes from a personal real experience. Copper prices decreased from $3.50 per pound in December 2012 to $2.00 per pound at the end of

2015; while molybdenum decreased from $12.00 per pound to $5.50 per pound in the same period. Many mines struggled to adapt to these changes in late 2015 and announced their upcoming shutdown. As mining engineer at an open-pit copper and molybdenum mine, I was part of a team that engineered mine plans that could potentially generate the highest NPV for the mine under very low commodity prices. Mining and processing plans were engineered, sent to the accounting department, and evaluated to obtain the NPV. Mining and metallurgical engineers would spend approximately three to five days of full-time work; after this, the accounting department would take one to two weeks conducting the final NPV evaluation, for a total process of eight to fifteen days. If the results were not favorable or as expected, a new plan would be created by the mining engineers, and sent again to the accounting department. The process would continue repeatedly until managers were able to determine which mine plan to follow. Approximately 20 to 25 plans were created and evaluated from late 2015 to June 2016. The excessive time spent on conducting long-complex financial models for each mine plan could have been prevented if the mining engineers were able to use a financial model that readily integrates faster evaluation techniques and reporting tools; these would allow them to quickly have an idea of how the redesigned mine plan would perform. If not favorable, they would continue readjusting the mine plan without sending it for an unnecessary final long-complex financial evaluation. Instead, only plans with promising results would be sent.

Corporate, publicly and prematurely, announced that the mine was going to shut down in June 2016 because the mine was not generating positive cash flow in late 2015; there was big pressure due to the market stress of very low copper and molybdenum prices in late 2015 and high debt by the company. This announcement happened without truly looking at all alternatives for possible mine and processing schedules; probably because evaluating new mine plans would take months, which if unfavorable, would make the mine lose more revenue. If the employees on-site were able to speed up the mine plan-evaluation process, maybe the company would have found a suitable plan an avoiding the announcement of the shutdown. The upcoming mine closure caused that miners worked with the distraction of the possibility of losing their jobs which could translate into personal safety problems and reduced efficiency of the mine. Moreover, many skilled people decided to look for other opportunities and left the company. After this announcement, engineers on site continued developing more mine plans in the hope of reversing corporate's decision and to allow the mine to continue operating beyond June 2016. In the end, improved mine plans were effectively implemented by mine operations changing corporate's decision about the closure, allowing the mine to continue operating beyond the original shutdown date. This project is important because it will increase efficiency to determine if an operating mine can implement changes that adjust to a different set of market or orebody conditions without the need of comprehensive financial analysis. Reducing the timeframe of uncertainty is done using faster evaluation techniques and quick reporting tools after a mine plan has been engineered. This faster turnaround will allow engineers to have an idea of how their plan will perform, and to determine if it is necessary to send it the accounting department for a long-complex NPV evaluation. This increase in efficiency reduces uncertainty which translates into less safety and production issues, and erroneous decisions leading to losses of revenue.

The methodology for this project includes a mixture of both qualitative and quantitative methods. This is to understand how the process, from generating a mine plan to evaluate it financially, can be streamed down to speed up financial evaluations as operating mines adjust to unexpected changes in commodity prices, exchange rates, orebody characteristics, and others. The qualitative component will be completed through documentary analysis, observations, and literary research in order to determine important aspects to evaluate a hypothetical operating mine. The name given to this imaginary mine study is *Nova Mina* which is set in Portugal. The quantitative component will be completed through the construction of a financial model for *Nova Mina* that incorporates tools for quick information analyzing and reporting, via VBA Macros in Microsoft Excel, that can easily reflect the flexibility of the mine to different production schedules which are created by mining engineers to adjust to unexpected set of conditions. A general idea of the information to be recollected for the hypothetical *Nova Mina* case comes from the *Agricola Mining* example presented on page 337 of the book "The Mining Valuation Handbook" (Rudenno, 2009). The resultant model is a Microsoft Excel workbook annexed to this document.

The resultant financial model will demonstrate that an organized and well-structure model for operating mines can be streamed down with VBA Macros and other short-form tools to conduct DCF and sensitivities analyses of mine plans in order to speed up the assessment of how the operating mine can adjust to unexpected changes in commodity prices, exchange rates, orebody characteristics, and others; this is to substitute conducting a thorough complex and long DCF for each mine plan that is created.

II.- SHORT-FORM EVALUATION TECHNIQUES FOR OPERATING MINES

Because changes can occur unexpectedly, it is very important for operating times to make it as easy as possible to implement change. Evaluations, though, are typically too comprehensive and time consuming. Therefore, as Ian Runge (1998, 187-192) describes, short-form evaluation techniques that help operating mines to sacrifice some imprecision in the calculations in exchange of quicker decision making under the stress of the changing conditions. If the market price for copper, for example, quickly drops, the mine needs to be able to react promptly to this new situation to perform positively and live up to the initial expectations of the project.

The issue with short-form evaluation techniques as a reference for decision makers lies in the characteristics overlooked by the technique itself. Consequently, decision maker will need to use his or her experience for situations that have not exactly ever matched the current conditions, with the help of the short-form evaluation techniques. Ian Runge (1998, 187-192) presents the most common short-form evaluation techniques as the following: "Strip Ratio;" "Focus on Production: Incremental Production;" "Focus on Production: Avoiding Loss of Production;" and "Focus on Capital." Moreover, based on my experience, there are other possible short-form techniques that can be implemented such as "High Grading" and "Production-Reduction;" the latest contradicting Runge's technique on avoiding loss of production. The fundamental economics of each will be presented in the next sub-sections. Ian Runge's "Strip Ratio" and "Focus on Production: Incremental Production," and tools based on my personal experience, "High Grading" and "Production-Reduction," will be incorporated for different scenarios of changing conditions in the financial model for the hypothetical case of *Nova Mina*.

A.- Strip Ratio

The strip ratio is the number of blocks of waste needed to be mined to mine one block of ore. This value is usually a good indicator of economic value for the operating mine because waste is related to cost and ore is related to revenue. "A low ratio means low costs in relation to revenue, therefore, is an indicator of relative profit," denotes Runge (1998, 188). Consequently, an operation with a low strip ratio will generally have lower costs than another mine with a higher strip ratio, depending on other factors such as grades of the ore blocks. While the strip ratio translates into easy calculations as a short-term technique, there are certain limitations such as mines having variations in dip and/or rock hardness, low strip ratio mines as most cost is associated to ore mining, the associated increased costs because of depth, and having different equipment types at the mine (Runge 1998, 189).

The strip ratio short-form technique will be applied to the hypothetical case *Nova Mina* because it has a strip ratio higher than 1, a consistent dip and hardness throughout the mine operation, and same equipment everywhere; nevertheless, adjustments will be made for the increased associated costs with depth of 25 cents per four benches.

B.- Focus on Production: Incremental Production

If mine output is intended to be increased to make the project more profitable, then only incremental investments need to be justified. A reason making mine expansions valid is that the knowledge of the orebody characteristics has become clearer and more reserves have been found. Limitations can occur. In the mining industry, there might be other ways to make an operation more profitable even with less or no production increase; nonetheless, these are usually overlooked by the culture of improving economics with more production. Ian Runge (1998, 190) explains: "Indeed, some of the best incremental investments in operating mines are investments that do not result in production increases." Such as it could be in slope optimization, mining efficiency and others that incur on savings. However, a bias affecting this kind of investment occurs because it is usually harder to demonstrate the source of revenue; which is much easier with increased production. The incremental production short-form technique will be conducted in the hypothetical case to incorporate newly discovered mining reserves that will be added to the new "Open Cut 4" for increased production with the investment of a new ball mill or by simply extending the life of the mine.

C.- Focus on Production: Avoiding Loss of Production

"For any given selling price (usually outside the mine operator's control anyway), loss of revenue equates exactly with loss of production" details Ian Runge (1998). Because of this, avoiding loss of production is considered very important at an operating mine; targets are usually set on production. The major problem with this approach is that it diminishes the perspective on advanced planning and prevention measures (Runge, 1998, 190). For example, slope movement from an unstable area is detected, stopping production from this specific area until the concern is controlled with prevention methods. This can be mistakenly seen as erroneous since production should be favored; nonetheless, controlling this area now has the potential of eliminating remediation costs later, impacting production even more.

D.- Focus on Capital

A focus of minimization of capital is important and should be analyzed carefully. Shareholders expect their investments to make money; consequently, the funding structure, risk, and diversification should be considered when allocating capital expenses. Projects with a highest return should be favored. Using alternatives to capital investments such as higher operating costs are more likely to have higher risk which can't be accepted by shareholders nor the organization (Runge, 1998, 192).

E.- High-Grading

High grading is when a company "changes the mine plan to extract the highest-grade material to increase short term profitability, or even just stay in business" (Cook 2013). If enough material is already exposed to active mining, the cut-off grade can be increased to process material with the most contained metal, leaving lower grade material unprocessed in a stockpile or unmined at all. Based on personal experience, this technique can greatly improve profitability as more metal is produced with less or equal mining, therefore reducing the cost per metal produced. Nevertheless, there are significant implication associated with high grading. The most important one is compromising future ability to mine out current low-grade ore reserves. Optimized mine plans balance out throughout the life of the mine high grade material with low grade to mine more metal. However, if all high-grade material is mined too quickly, low grade material can become uneconomical to mine in the future. Therefore, cautious planning should be conducted before approaching this technique to understand future possible consequences. "The effect to the ultimate NPV of a deposit varies, and in some instances high grading may ultimately have no real negative effect" (Cook and Wilson, 2013). The High-Grading technique will be applied to the *Nova Mina* case to determine if it increases NPV.

F.- Production-Reduction

Reducing the mining rates, including the reduction in metal production, can be an alternative in order to reduce losses. If a mine is affected by low commodity prices and is operating at a loss, reducing metal production can reduce those losses. Moreover, if the mine has a positive cashflow but it is extremely low, reducing metal production and delaying it for the future when commodity prices are higher could potentially offset the costs associated with time value of money. A major issue with this technique is that reducing production considerably might require layoffs and ramping back up production in the future might be very challenging, even if prices are very good, because of the strenuous time required to hire back all personnel needed. In addition, the company can be pressured by investors and debtholders to avoid this alternative as they demand their money back as soon as possible. Finally, even if this alternative to reduce production is approved, the risk that prices do not increase as expected in the future will always be present. This technique of deferring production for future years when prices are expected to increase or go back to recent historic levels will be applied to the Nova Mina case.

IV.- FINANCIAL MODEL

A.- Assumptions

The model layout and structure should be simple, dynamic, and flexible. To start the development of the financial model, it is important to determine a set of assumptions related to mining projects. The first element is to assume a certain life of mine based on technical reports and current reserves; it is crucial to build a flexible timing structure for scalability and flexibility in case further reserves could potentially be added as more drilling has confirmed economic viability of extraction.

Conversion rates are also to be included in the assumptions to consistently model the finances of project in the correct mineral units from beginning to end. Currency exchange rates and metal prices are crucial in the profitability of a project. Because most commodities are sold in US dollars, the impact of exchange rates for projects governed by another currency is very significant. Moreover, "commodity prices are also beyond the control of mining companies and, as budgets and plans are based on future commodity prices, the uncertainty adds to the difficulty of future planning" (Rudenno, 2009, 193). Consequently, it is important to incorporate pricing and exchange rates flexibility.

In the assumptions, it is also important to include the mine plan and reserves table of the project. Based on the processing type, the ore tons processed per year are input throughout the life of the mine with its associated grade and recovery; in addition, include the reserves and resources tons per metal are included to understand the contained metal in the deposit. Also, it is crucial to add the constraints based on the type of processing, as per capacity per year (Corporate Finance Institute, 2017). Royalties associated to the metal produced need to be identified; royalties could be as "a fixed cost-per-unit of production, or ad valorem royalties" (Rudenno, 2009, 214). Other assumptions to be used from the technical report are operating, capital, reclamation, financial, and acquisition costs. In addition, the discount rate and working capital relevant to the project should be included. These assumptions are solely based on the technical reports such as feasibility studies. In depth analysis could be also implemented based on the level of detail desired for the model. For the hypothetical case of Nova Mina, all the elements mentioned above are represented in the "Assumptions" tab in the model for which the user can easily identify colored in yellow the items that are inputs to the model, including some for comments related to the case study.

B.- Mining Section

The mining and mineral processing, milling or leaching, schedules should be included in the Mining Section. The mining schedule should include the mineral inventory, and ore and waste total tons mined per year with their respective mineral grades to calculate the contained metal. The milling or leaching schedule should include the ore feed per year, associated recoveries from processing, payability rates, and final payable metal produced (Corporate Finance Institute, 2017). It is important to analyze different production schedules from a mining engineering perspective to determine the impact on revenue from multiple approaches. Therefore, an appropriate setup of the spreadsheet that requires no manual inputs is important. That way, based on the reserves and production assumptions, it can quickly shift from different production schedules to determine impacts on revenue, always considering risks associated with production expansion (Corality, 2017). For the hypothetical *Nova Mina* model, the "Mining" tab includes a table that was carefully set up with the information mentioned above. This table reads the inputs from the "Assumptions" tab and elaborates the mining and production schedule automatically. To add flexibility, a few more years were added than required as per the current base case. This will allow easy computation for when the mine needs to increment its lifetime; this will be seen in the scenario when *Nova Mina* increments production for later years beyond the original life of mine.

C.- Financial Statement Section

This section includes revenues and royalties, operating and capital costs, EBITDA to net income, and changes in operating capital. The revenue is simply the production per year multiplied by the corresponding commodity price. Royalties could be a percentage of the gross revenue; for *Nova Mina* a 4% Portuguese government royalty has been applied based on a Reuters article (Cunha Lima and Ribeiro, 2012). The operating costs are obtained based mostly on the mined and processed tons. If there are byproduct credits, these are compensated in the operating costs; for *Nova Mina*, operating costs were based on an article by S&P Global in which the average costs per pound of copper produced in the EU is US$1.70 (Webb and Farooki, 2017). Capital costs related to the mine project should be also included in this section, and can include new infrastructure, investments for expansion, and others such as pumps, equipment replacement, etc; for *Nova Mina*, capital costs were based out of a project in Arizona with similar production rates (Bush, 2016). Depreciation, debt repayment and associated interest's costs are to be included depending how much the project has been financed by debt that needs to be repaid to the debtholders, which reduces tax payments. Depreciation is the tax allowance for wearing out mining and processing equipment. For example, a haul truck that costs $3 million and has a 10 year-life will depreciate $0.33 million each year if the straight-line method is applied, which is the case for *Nova Mina*. As the equipment loses its value, the company will pay less taxes. "Depletion is the equivalent to depreciation for deposit reserves," explains Ian Runge (1998, 57). As higher grades get mined out, the deposit becomes less valuable and more challenging as the head grades decrease. Tax allowances because of depletion is implemented by taxing authorities in certain countries. Working capital is the "investment" needed to fill up a warehouse for spare parts or to have advance workings such as stockpiles. These are not tax deductible and do not depreciate by most authorities, making it a cashflow outflow in the beginning but a cashflow inflow at the end. Finally, the amount of money to be paid to the government based on the taxable profit is called taxation (Runge 1998, 55); for Nova Mina, the 21% corporate tax of Portugal was applied for the life of the project (KPMG, 2017). If not mentioned, the rest of assumptions for Nova Mina were based out of the Agricola Mining example (Rudenno, 2009).

D.- DCF Valuation

Once the free cash flow has been calculated in the previous section, the discounted cash flow (DCF) methodology is used to calculate the NPV of the future cash streams. This is to represent the option that a mining company has "over its ore reserves and mineral resources" under different operating costs and commodity prices. Using the correct discount factor on future cash flows streams, it is possible to determine the value of the operating mine; consequently, it helps to decide if an investment should go based on the NPV (Rudenno 2009). Usually in mining, the discount rate applied is not determined by the mine planning engineers; it is usually dictated by board of directors or senior management. The composition of a discount rate used for mining projects is described in the book *Mining Economics and Strategy* by Ian C. Runge (1998, 59):

1. The interest rate applicable for zero-risk investment in the respective country.
2. "Allowances for the cost of capital" which includes both equity and debt funding.
3. The relative mix of the debt and equity; financial instruments to reduce the blurriness of higher debt:equity rations, which reduce funding costs but increases financial risks.
4. "Allowances for the finance risk:" Lenders looking at cash flows surplus from the project and chances of being repaid the loan.
5. "Allowances for the technical risk:" Geotechnical problems arising, lower possible ore grades, and the commitment of the mining company to use technology guaranteeing the future cash flows.
6. "Allowances for the fact that the company is more 'locked in' to its investment:" Money invested in money is difficult to be retrieved; therefore, incurs in a premium.
7. Allowances that the returns of the current project can cover the study of other potential projects that could replace the current one in the future, assuring long-term business.

Once a discount rate has been defined, the cashflow stream can be discounted to find the NPV of the project. If there are two or more possible production plans for the mine project involving different capital and operating costs, a decision will need to be made on which alternative to invest. This is usually determined by comparing the NPVs, IRRs, and payback periods of each project. The highest NPV is usually desired and the same goes for the IRR; however, it is possible that the two provide a different answer. For example, a small project with low capital investment and shorter timeframe might have a higher IRR but lower NPV than a long-large heavy capital investment mine. If this occurs, it is important to understand what it would be done with the money still available from pursuing the small project. Making both alternatives match the same period is important to understand which one to pursue (Runge 1998, 64). For

Nova Mina, a cost of capital equal to 8% was applied. This rate was based on different mines in Portugal and Europe applying an 8% discount rate for copper projects. Lundin's Neves Corvo Mine in Portugal uses an 8% discount rate for its DCF analysis (Newall 2017, 208) and also S&P Global Market Intelligence reports that, out of 55 copper mines, the average cost of capital used is 8% (Manzella, 2017). *Nova Mina* has an initiating hypothetical debt outstanding of 240 million euros at a cost of debt of 8%. Considering the tax rate of 21%, and total equity of 750 million euros, the cost of equity would be approximately 8.5% by using the WACC equation.

E.- Sensitivity Analysis

It is critical to conduct in any investment evaluation different sensitivity analysis of the inputs that impact the return of the mining project. This allows the investor to comprehend thoroughly different scenarios under which the project could be in, and how much these different circumstances affect the return of the project. Two important characteristics are to be considered for a sensitivity analysis:

1. Even if an input has a big impact on the return of the project, a sensitivity analysis is irrelevant of the input's likelihood of happening is very little.
2. "Sensitivity analyses invoke the ceteris paribus assumption." This means that an input can only change keeping all other inputs and conditions equal.

Because of the above, sensitivity analyses are of limited and should not be used as completely true. Nonetheless, simple sensitivity analyses establish the base for probabilistic analysis and relative sensitivity analysis. The first one is of limited use in mining because of the difficulties on estimating the likelihood of an input to change. The second one, however, is of great use as it can help to compare how sensitive the return or payback period is to a change of a certain input among two or more mining projects. All other things equal, if project A has more sensitivity to change in commodity price than project B, then project B would be preferred. Moreover, sensitivity analyses help to understand how much a controllable input, such as operating costs, need to change to offset the negative impact of uncontrollable inputs, such as a decrease in commodity prices or increase in taxes (Runge, 1998, 138).

In the mining industry, most sensitivity analyses are performed on the following: "product selling prices, some production rate variations… exchange rates, capital cost changes, fuel oil prices, delays in revenues after start-up (Runge, 1998, 185)." In an operating mine project, it is expected to have positive cash flows for the remaining of the mine; consequently, the IRR cannot be calculated. For the *Nova Mina* hypothetical case, the sensitivity analyses are built into the model using macros; for each change in the "Assumptions," the sensitivity analyses can be performed simply using a button. The sensitivity analyses for *Nova Mina* are included in the report generated for each case ran in the model.

F.- Summary Charts and Graphs

Summary charts and graphs are an important tool to understand the outputs given by the financial model for decision making. Graphs usually displayed by mining companies include: Free Cash Flow, Break-even, and Production. Charts and graphs to be reported must be dynamic and flexible to display results after each input is modified; these features will allow quick and unbias reporting. Clear and clean graphing also allows decision makers to interpret what is important and avoid wasting time in useless information.

G.- Financial Model Features

The model developed for this project and used to conduct the analyses presented in the next section includes additional features that facilitates economics reporting. The financial model has the following tabs: "Assumptions," "Mining," "DCF," "Graphs," Sensitivity_Analysis," and "Report Maker." The last tab creates a summary of the whole model run in a neat and organized format. Macros were developed to generate a PDF report which can be saved under the user's preferred location and file name. Moreover, there are macros developed to conduct sensitivity analyses on different inputs. All graphs and charts are fully automated and update as the inputs in the "Assumptions" tab are changed. Finally, there is a button to remind users to save their work under different names to avoid over-writing previous study cases.

V.- HYPOTHETICAL CASE: NOVA MINA

Nova Mina is a hypothetical operating copper mine in Portugal in the Iberian Pyrite Belt; the mine has already been in production for 18 years. Currently, the open pit is being operated by a contractor who provides its own equipment and labor and follows mine plans engineered by personnel employed directly by the mine. Nova Mina mines sulfides from a porphyry copper deposit; leaching tests have shown very low recoveries making this processing method uneconomical. Consequently, a mill concentrator was built at the beginning of the project 18 years ago and is a sunk cost. Table 1 shows other characteristics of the mine and inputs used for its mine plan. Figure 1 shows the cumulative Net Present Value for the remaining 11 years of operation which is € 1,597 million euros at an 8 percent discount rate. At an operating mine, conditions can change at any time, primarily in the commodity prices.

Table 1.- Input Parameters

Operating Costs			
Ore Mining Cost	€	1.90	per tonne
Waste Mining Cost	€	2.00	per tonne
Depth-Related Increased Cost	€	0.25	per year
Ore Processing Cost	€	6.20	per tonne
Downstream Cu Cost	€	1,025	per tonne of saleable metal
Rates and Others			
Mill Recovery Rate		91%	
Smelter Recovery Rate		97%	
Mill Production Rate Capacity		63	ktonnes per day
€ : US$ Long-Term Exchange Rate		1.17	
Portuguese Gov Royalty Rate		4%	of revenue
Tax Rate		21%	
Discount Rate (WACC)		8%	
Debt Outstanding (Jan-2018)	€	240	million
Interest Rate		8%	
Depreciation Carried Forward Jan-2018	€	280	million

Year	Copper Price ($/lb)	Capital Expenditure (Millions)	Working Capital (Millions)
2018	$ 2.78	€ 33	€ -
2019	$ 2.81	€ 30	€ -
2020	$ 2.84	€ 33	€ -
2021	$ 2.87	€ 30	€ 6
2022	$ 2.90	€ 33	€ -
2023	$ 2.94	€ 27	€ -
2024	$ 2.97	€ 29	€ -
2025	$ 3.00	€ 25	€ -
2026	$ 3.18	€ 22	€ -
2027	$ 3.18	€ 20	€ -
2028	$ 3.18	€ 17	€ (6)
2029	$ 3.18	€ -	€ -
2030	$ 3.18	€ -	€ -

For *Nova Mina*, the changing conditions are to occur in the beginning of 2018, the present, to demonstrate how the mine can adjust its production schedule to changes. For each case, a PDF report will be generated and is annexed to this project. The tool developed can help decision makers to make some adjustments to the current mine plan that improve the economics of the project. The set of constraints will be unique to each mine; for *Nova Mina*, hypothetical constraints are mentioned in each report generated.

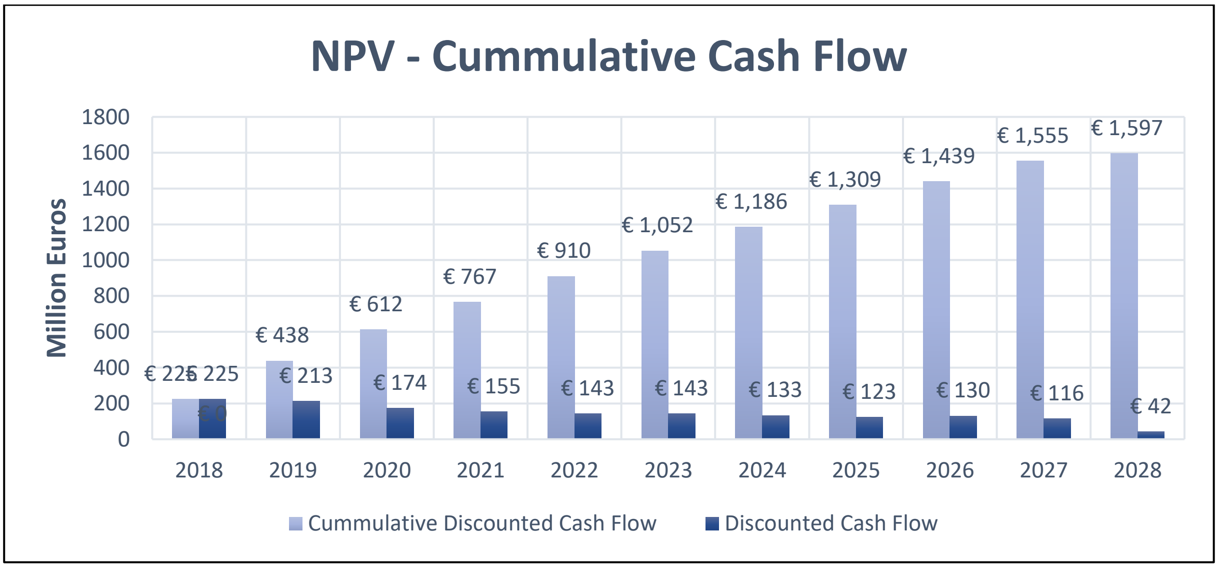

Figure 1. Cumulative Net Present Value over the Life of Mine

A.- Scenario 1: Decrease in Copper Prices

Under this scenario, the market price for copper price has fallen 30 per cent and are expected to stay this low until 2020, reaching prices like those experienced in late 2015 which were under US$ 2 per pound. However, the prices are expected to increase from 2021 to 2030, still at 10% lower than the base case, as automobile manufacturers are continued to increase electrical vehicles production (Lienert – Kyodo, 2017) which require substantially more copper than a regular car. Using, the financial model developed, the mine can quickly modify the copper prices, make some changes, and generate a report to rapidly compare results to the base case. Under this copper price decline, the NPV decreases to € 779 million which is only 48% of the original NPV. Because of the big impact to the NPV, the mine has decided to conduct different studies to improve the economics of the project under this lower copper prices.

Based on the short-form technique of strip ratio, it was studied for *Nova Mina* to modify the mining production scheduled to reduce the waste mining in the earlier years and to delay this stripping costs to year 2021 and beyond when copper prices are expected to increase. *Nova Mina* can conduct this because the contractor is able to reduce production up to 15% during 2018-2021 and to add back this stripping equally to the remaining years. A mining contractor and big mining companies have abilities to transfer mine equipment to other sites, or to rent equipment for shorter periods of time when copper prices improve. However, changes in contracts, or additional equipment rental can after future mining costs. After conducting the analysis, it was determined that the NPV stays similar to € 778 million euros. The delaying of the costs, improve the EBITDA per pound produced in the earlier years; however, the increased mining costs associated with delaying stripping offset the benefits. This analysis, nonetheless, helps the mine to understand, that if at some point the prices were to radically fall and make a year a negative cash flow, delaying stripping could be an option without affecting the overall NPV and turning a negative cash flow for a certain year to positive.

Using the technique of Production-Reduction, it was also studied for *Nova Mina* the possibility of reducing copper production rates by decreases ore production and keep normal rates for waste stripping. It is known from the first study above that delaying stripping does not generate benefit, but delaying copper production is beneficial because the market is expected to increase demand for copper in 2021 which leads to higher copper prices. Therefore, it is of interest if selling copper in the future is better than selling it today at a lower price. For *Nova Mina*, it is possible to reduce ore mill throughput by 5 percent for 2018, 2019, and 2020; and increase the same percentage in 2021, 2022, and 2023 without making modifications to the processing circuit. The NPV obtained by applying these changes is € 788 million which is approximately € 9 million more than without the changes. It is important to study comprehensively the copper market in current and future years to establish strategies like this one. In this case, prices are expected to increase in 2021 due to the mass manufacturing of electrical vehicles that many automakers will be implementing. A more abrupt study that could be conducted is to reduce production to 75% or 50%, as more copper would be delayed and sold in future years when prices are expected to be better. However, this approach needs to be carefully applied as reduction in workforce would be required, and it is important to consider how difficult it would be to ramp-up again when prices are high again. Moreover, prices not recovering as expected can negatively impact the NPV.

The possibility of high grading is also studied for Nova Mina. The objective is to increase the internal cut-off grade for mostly 2018 and 2019 to increase copper production and reduce the total cost per pound of copper in those periods as commodity prices are low. This, however, decreases the head grade for from 2020 through 2023, increasing the cost per pound in those years. Overall grade of the reserves must stay the same at 0.753% copper. The grade was modified for the first cut as it would be mining the highest grade from the second cut in 2018 and 2019, increasing the grade from 0.765% to 0.820%. This decreases the grade from

2020 through 2023 from 0.732% to 0.698%. Even though the EBITDA per pound increases from US$ 0.51 to US$ 0.57 in 2018, which translates into €22 million, and from US$ 0.48 to US$ 0.54 in 2019, which translates into €20 million, the NPV for the entire project decreases €3 million to €776 million. This demonstrates that for Nova Mina should avoid high grading as it affects the NPV of the whole project. This is a good alternative if prices were to decrease tremendously making the cash flow for the current year negative and there is pressure from debtholders; it might lead to an overall decrease in NPV but can reduce pressure of bankruptcy.

Finally, another short-evaluation technique that is quickly approached in the model relates to focusing on capital costs. This technique is, probably, the easiest to understand for many decision makers. If capital costs can be redistributed appropriately through later years, the NPV will likely increase as cost of one dollar invested in the future is less than one dollar invested today. However, this easy concept to understand can carry many unforeseen issues making delays in capital expenditure costlier to the company in the long run. For example, if *Nova Mina* requires a water pump to remove water covering ore reserves by a certain date, delaying the capital costs of buying the pump can result in the mine not being able to meet production plans as there might be still water covering ore reserves, making the process more expensive. No hypothetical scenario was built for *Nova Mina* using this technique; nonetheless, it is important to be mentioned that capital costs can quickly be adjusted in the model if decision makers find an opportunity to reduce or delay capital expenses without impacting the overall mine plan. Table 2 shows the resultant NPV after each case was applied to the model:

Table 2.- NPV Results for the Different Cases in Scenario 1

Scenario 1: Decrease in Cu Prices		
Case	**NPV (Millions)**	
Same Plan	€	779
High Grading	€	776
Reducing Cu Production	€	788
Strip Ratio	€	778
Focus on Capital Costs	€	779

The conclusions obtained from "Scenario 1: Decrease in Copper Prices" are that the short-form technique of strip ratio can be applied easily to the calculations; nonetheless, it is important to understand its limitations, and that the constraints regarding how much the strip ratio can be altered. In the case of *Nova Mina*, there was no effect on delaying waste stripping in the effort to increase NPV because of the increase in equipment needs in the future. A mine plan will typically try to smooth out the total tons mined throughout the years to maintain similar equipment needs throughout the life of the mine. On the other hand, there was an improvement to the NPV by delaying ore production to years when the metal price is higher as expected because of large automakers plans. High grading can increase temporarily cash flows for certain periods; however, for Nova Mina, there is a negative impact on the overall NPV. Finally, focusing on capital costs is another short-form technique that can create tremendous value to the mine if appropriate opportunities are found to reduce or delay capital expenses without compromising future mine plans.

B.- Scenario 2: Discovery of Additional Ore Reserves

Under this scenario and original price conditions, additional ore reserves have been measured next to the current deposit. Currently in the mining industry, brownfield projects are taking priority over greenfield projects due to stricter permits required for new mines and complexity involved compared to extending resources at an already existing operation (Whiting and Schodde, 2006). Therefore, it was assumed that *Nova Mina* would focus exploration around its property in hopes of increasing reserves. Recent drilling of 31 cross sections has helped to determine that there are approximately an additional 40 million tonnes of ore at an average copper grade of 0.604 percent. This additional material would be mined from a different pit named "Open Cut 4." This is input in the model as additional 14 ore blocks with the copper grade mentioned above and 11 waste blocks in cross-section results. Figure 2 displays the location of the additional reserves. Two scenarios are studied for *Nova Mina* to determine which approach would create more value for the company; either increasing life of mine or increasing production rate with the investment of additional mill capacity.

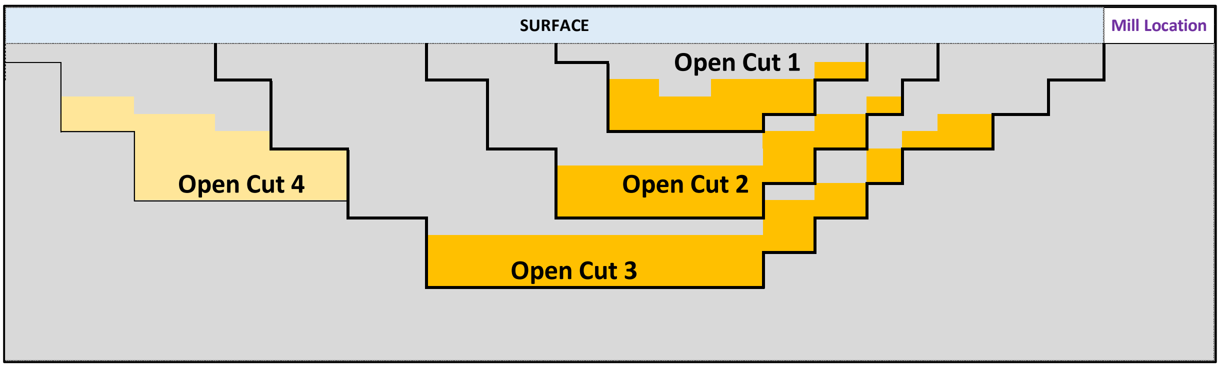

Figure 2. Additional 40 Million Tonnes added as Open Cut 4 to Nova Mina.

Under the first case, it is studied the NPV of adding the additional reserves to the end of the current mine plan in order to extend life of mine. The development of Open Cut 4 at the same mill rates translates extending the life of mine for two more years. This incurs in additional capital costs of € 5 million for both 2027 and 2028, and € 20 million for 2029 and € 17 million for 2030. The NPV becomes € 1,714 million which is approximately an increase of 7.3% higher compared to the original € 1,597 million before the discovery of new reserves.

Under the second case, it is studied the NPV of investing € 187 million in 2018 to increase the mill capacity starting in 2020 for an additional 7 ktonnes per day. In addition, because life of mine is extended to 2029, additional capital costs of € 2 million for 2027, € 3 million in 2028, and € 17 million for 2029. The resultant NPV of this analysis is equal to € 1,635 million which is higher than before the addition of the new reserves by approximately 2.4%. Nevertheless, it is less than the previous case of not adding extra mill capacity but rather just continue at the same capacity and extend life of mine. Table 3 shows the resultant NPV after each case was applied to the model:

Table 3.- NPV Results for the Different Cases in Scenario 2

Scenario 2: Discovery of Additional Ore Reserves		
Case	**NPV (Millions)**	
Extended Life of Mine	€	1,714
Increased Mill Rate	€	1,635

The conclusions obtained from “Scenario 2: Discovery of Additional Ore Reserves” are that different cases can quickly be evaluated in the model, making use of the short-technique of focusing in incremental production. For *Nova Mina*, it was determined that it is more beneficial to extend life of mine at the same time than investing in additional mill capacity. The tool allows decision makers to quickly understand where further detailed analyses should be focused on.

The main takeaway from the two scenarios evaluated for *Nova Mina* is that a tool available for mining engineers that readily integrates a financial model and quick reporting can greatly facilitate decision making and to understand which technique the engineers should develop a more detailed plan to be sent to the financing and accounting departments for a thorough DCF evaluation. If commodity prices are slumping, the tool, for example, determines that engineering should focus on delaying copper production for when prices are expected to increase. If new reserves have been found, engineering should focus on extending its life of mine and working on getting the appropriate permits.

VI.- CONCLUSION

The model developed is a tool that mine engineers and managers can utilize to quickly asses how their operating mine can adjust to changing conditions in the market, orebody, processing, governmental, environmental and more. An operating mine has already a lot of sunk costs, and the key to success is to make sure decision making is prompt and accurate when unexpected conditions arise. To do this, managers and engineers need to be able to process the affecting changes on their mine quick enough to adjust to the new conditions before the mine becomes unprofitable. The model based on short-form techniques accepts different inputs on different possible conditions and automatically elaborates a rough mining schedule that is evaluated with a DCF and which also features different sensitivity analyses. Moreover, the model allows the user to create a PDF report of the evaluation to quickly document and compare among different set of conditions how the mine can adjust to changes. The hypothetical case *Nova Mina* displays how on two different scenarios, the tool can become a quick reference to understand the new settings without the need of long and complex financial analyses. However, this quick turnaround comes with limitations such as less detailed mining schedules, DCF analyses, and refining in the inputs. Moreover, the model created is based only for open pit mining and not to other types of mining; it particularly targets copper mining. Also, the model is limited to the inputs defined in the “Assumptions” tab; more parameters could be needed for better accuracy. Despite these limitations, the model is a quick reference tool allowing the interested parties to focus on studies that appear more beneficial to the mine; therefore, reducing efforts on creating mine plans or refining inputs on studies that at the end will not make an impact as positive as some specific ones that were identified by using the tool and techniques presented.

Based on my experience, an approach similar to *Nova Mina’s* reduces delays in conditions that can be extremely stressful; this increased efficiency allows operating mines to assess its abilities to adjust to unexpected changes. This will allow to quickly focus attention on refining inputs and elaborating more detailed production plans that allow the mine to overcome the changes. Future work involves applying this model to a real operating mine with more detailed information to capture actual and real benefits.

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